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Neural Network Method for Determination of Components of Angle Measurement Errors

In the paper the method based on the usage of neural networks for determination of components of angle measurement errors is presented. The main feature of this one is the possibility of the neural networks to perform parallel processing of the measuring data in real time. Network was trained and its performance was tested by using of simulation results and real multiple observations when measuring the plane angle of the24-faces prisms.

Modern goniometric systems, which are complex software and hardware complexes [1], are considered to be the most accurate optical measuring systems used for contactless measurement of angles in various industries, navigation, research, testing and calibration laboratories, as well as metrology centers. For example, they can be used for the adjustment of navigational sensory elements (accelerometers or gravimeters).

The main tendency of the development of modern measuring technology remains the desire to increase the efficiency of its functioning. Some of the performance indicators of the measuring systems are accuracy, reliability and performance of measurements. Herewith, an increase in accuracy is possible due to the improvement of the measurement methods, computational algorithms and other procedures, that allows to provide the given accuracy in cheaper but nevertheless not less effective ways. One of these ways can be neural network method for determination of angle measuring errors (random and systematic) which is proposed [2].

The essence of the proposed method is that for any measurements, including goniometric ones, there are methodological, instrumental and subjective errors that manifest themselves in the measuring results as systematic and random components [3] which are changing in time as non-stationary random process [4].

There are a lot of well-known methods for data processing and also systematic and random components of the measuring errors. These methods are widely used, well-grounded, perfectly formalized as well as principally different. They are regulated by the relevant normative documents [5, 6]

Therefore, it is necessary to analyze the measurement results to determine exactly which component of the error is contained in the set of measurement data. Because correct determination of the error’s component in the measuring results will allow applying appropriate methods of the measurement data processing correctly in the future to avoid mistakes and inaccuracies, and, as a consequence to improve the accuracy and reliability of the measurements as a whole.

To achieve this measuring data from goniometer in the digital form is sent to the input of artificial neural network (ANN), which is pre-trained in supervised mode to recognize random and systematic errors. Fig. 1 shows the principle of supply digitized measurement data to the input of ANN for processing. As a technical result of this we achieve productivity increasing and improving accuracy of angle measuring as a whole.

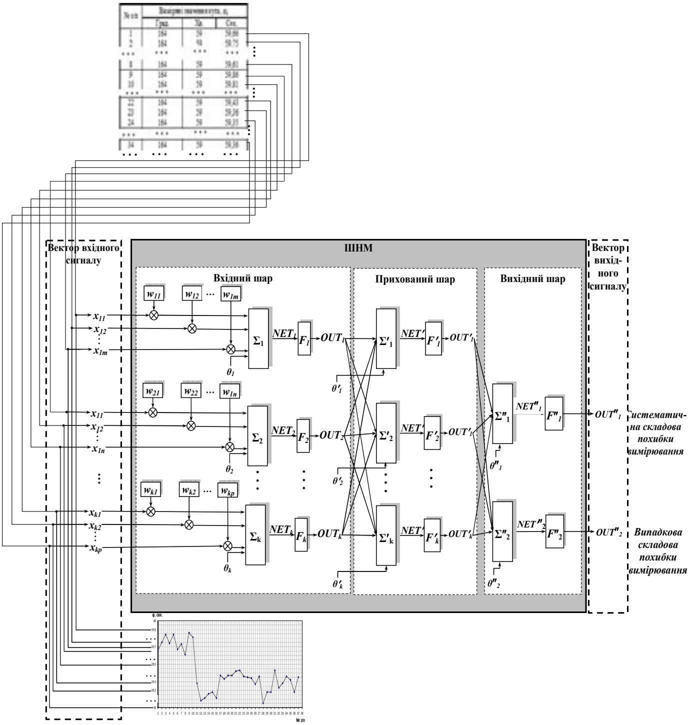

Fig. 1. Principle of supply digitized measurement data to the input of ANN

At the same time, productivity increasing of determining the components of measurement errors with the use ANN is conditioned by the fact that for digitized measuring data parallel processing method is used which is implemented by ANN. At the same time, the processing speed is achieved by the fact that the information submitted to the ANN is processed by it all simultaneously (Fig. 1), but not consistently. Data processing time depends on technical features of ANN (clock frequency, bit rate, number of hidden layer neurons, etc.) and dimension of the measurement information determined by the required number of measurements.

Accuracy improvement of this method is conditioned by the fact that ANN detects and recognize random and systematic components of the measuring errors. This determines the right choice and the application of appropriate known methods of their normalization and compensation, which are fundamentally different. In particular, the systematic components of the error can be completely eliminated by the introduction of the corresponding corrections, and random – can be significantly reduced by increasing the number of observations. ANN which is used for this according to the type of neural algorithms, nonlinear transformations and the possibility of construction, can be implemented, for example, a reprogrammed neuroprocessor with adjustable structure of neurons according to one of the known models (multilayer perceptron, Hopfield network, etc.) or a software model based on known neurotransmitters.

ANN is trained according to the supervised learning algorithm by the back-propagation as follows. Training Database contains the set of examples which is 60 results of multifaceted prisms examinations CMFP-6, CMFP-8, CMFP-10, CMFP-12, CMFP-18, CMFP-24, which are used for tuning equipment for angle measurement and for direct measurement of industrial angles products GOST 2875-88 (Table 1, Table 2). Each example of training set $\langle X, Y\rangle$, according to the technical requirements is a vector of ANN input signals $X = (X_1, X_2, \dots, X_S)$, which is set of results of multiple measuring of plane angle of corresponding multifaceted prism in its examination (Table 1) and vector of the output signals $Y = (Y_1, Y_2, \dots, Y_N)$, which is a result of corresponding component (systematic or random) of measuring errors detection in the set of results of multiple measurements of the plane angle of the corresponding multifaceted prism (Table 2).

Table 1

The part of the training set according to the results of plane angles measurement which were done with working and standard means for adjusting and tuning angle measurement equipment as well as direct measuring of industrial products angles GOST 2875-88

Example Code in Database	**Input vector $X=\{x_k \mid k=\overline{1;40}\}$ of measured value of the angle, φ_k, sec.**									
	from x_1 to x_{10}									
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}
CMFP-24/1	59,66	59,75	59,84	59,74	59,84	59,67	59,73	59,61	59,86	59,81
CMFP -24/1	60,0003	60,0006	60,0009	60,0012	60,0015	60,0018	60,0021	60,0024	60,0027	60,003
…	…									
CMFP -24/9	58,5003	58,5006	58,5009	58,5012	58,5015	58,5018	58,5021	58,5024	58,5027	58,503
CMFP-24/10	57,7003	57,7006	57,7009	57,7012	57,7015	57,7018	57,7021	57,7024	57,7027	57,703
	…									
	from x_{31} to x_{40}									
	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}	x_{36}	x_{37}	x_{38}	x_{39}	x_{40}
CMFP -24/1	59,43	59,23	59,28	59,36	59,32	59,18	59,35	59,03	58,91	59,12
CMFP -24/1	60,0093	60,0096	60,0099	60,0102	60,0105	60,0108	60,0111	60,0114	60,0117	60,012
…	…									
CMFP -24/9	58,5093	58,5096	58,5099	58,5102	58,5105	58,5108	58,5111	58,5114	58,5117	58,512
CMFP-24/10	57,7093	57,7096	57,7099	57,7102	57,7105	57,7108	57,7111	57,7114	57,7117	57,712

After that the data from training database are sent in serial mode to the input of ANN with the following calculation of the error E. The last one reflects the value of deviation of the actual signal value $Y' = (Y'_1, Y'_2, \dots, Y'_N)$ at the input of ANN from the expected one $Y = (Y_1, Y_2, \dots, Y_N)$. In case of unsatisfactory training results the value of the hidden layer can be changed.

A result of the experimental study of the change of ANN's error, depending on the number of hidden layers of the neurons, is presented at the Figure 2.

Table 2

The part of output vector of the training set according to the results of plane angles measurement which were done with working and standard means for adjusting and tuning angle measurement equipment as well as direct measuring of industrial products angles GOST 2875-88

Example code of the Database according to Table 1	**Value of the Fischer criterion**			**Note**	**Output vector**	
	Calculated F	**Table value F_q**				
		$F_{0,01} \mid P=0,99$	$F_{0,05} \mid P=0,95$		y_1	y_2
CMFP-24 /1	4,03	4,41	2,28	Probability of the random error 99%, systematic – 95%	0	1
CMFP-24 /2	18,1818	4,41	2,28	There is a systematic error	1	0
…						
CMFP-24 /9	18,1818	4,41	2,28	There is a systematic error	1	0
CMFP-24 /10	0,1029	4,41	2,28	There is a systematic error	1	0
….						
CMFP-10 /57	0,0998	4,41	2,28	There is a random error	0	1
….						
CMFP-10 /60	18,1818	4,41	2,28	There is a systematic error	1	0

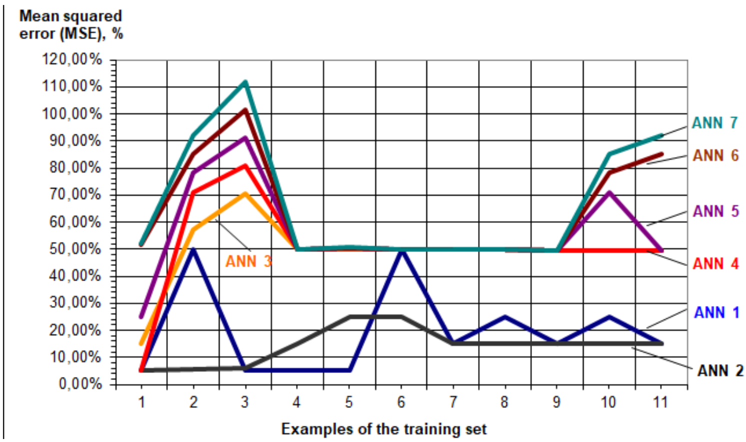

Figure 2. The diagram of changing of the error value E for the ANN with different dimension of the hidden layer: ANN 1 – input layer – 40 neurons, output layer – 2 neurons, hidden layer – 40 neurons; ANN 2 – input layer – 40 neurons, output layer – 2 neurons, hidden layer – 50 neurons; ANN 3 – input layer – 40 neurons, output layer – 2 neurons, hidden layer – 67 neurons; ANN 4 – input layer – 37 neurons, output layer – 2 neurons, hidden layer – 100 neurons; ANN 5 – inout layer – 40 neurons, output layer – 2 neurons, hidden layer – 20 neurons; ANN 6 – input layer – 37 neurons, output layer – 2 neurons, hidden layer – 1 neuron

As shown above the ANN 2 can be used for determination of components of angle measurement errors. ANN 2 has the following topology: number of inputs – 40 neurons, number of outputs – 2 neurons, number neurons in hidden layer – 50 neurons, number of hidden layer – 1. This ANN determined random component of the measurement error according to the multiple measurement results ($N = 37$) in 2 second.

Conclusion. The usage of artificial neural networks allows to decrease complexity as well as to increase productivity of detection of the systematic and random components of the measurement errors.

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